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(54) **INSTRUMENTATION SPARK PLUG**

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(52) **U.S. Cl.** **374/121**

(58) **Field of Search** 374/121, 141, 374/144, 124; 73/35, 115, 116

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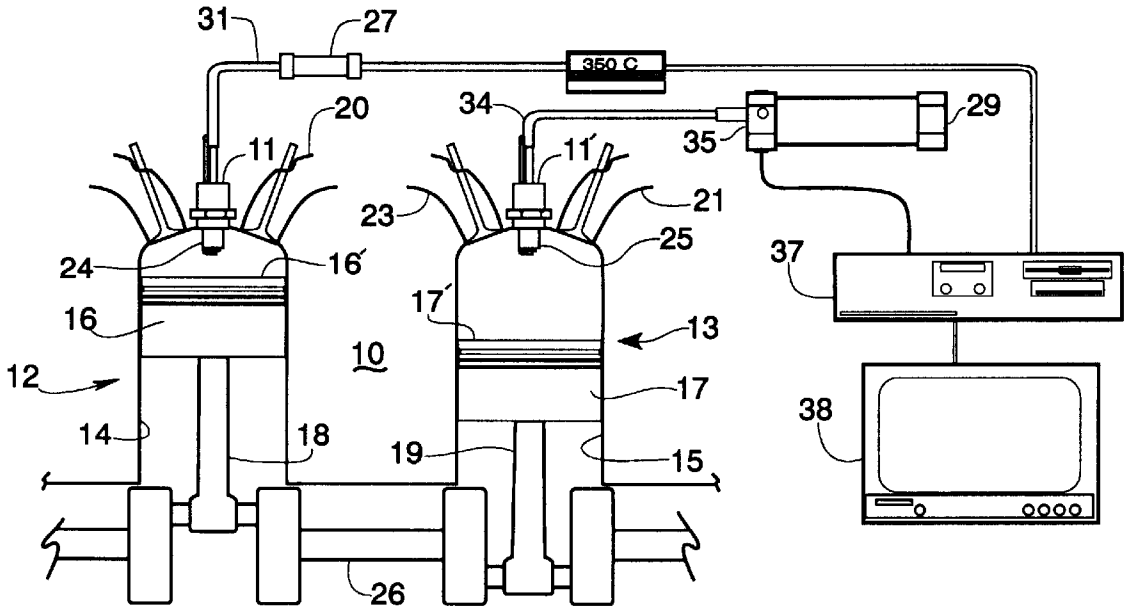
(57) **ABSTRACT**

A spark plug system for measuring the thermal profile across the surface of a piston in an operating internal combustion engine in characterizing the combustion process within a combustion chamber of the engine is described that includes a specially constructed spark plug containing a coherent fiber optic bundle and lens system optically connected to a remote sensing thermometer and high-speed triggerable imaging infrared video camera.

12 Claims, 2 Drawing Sheets



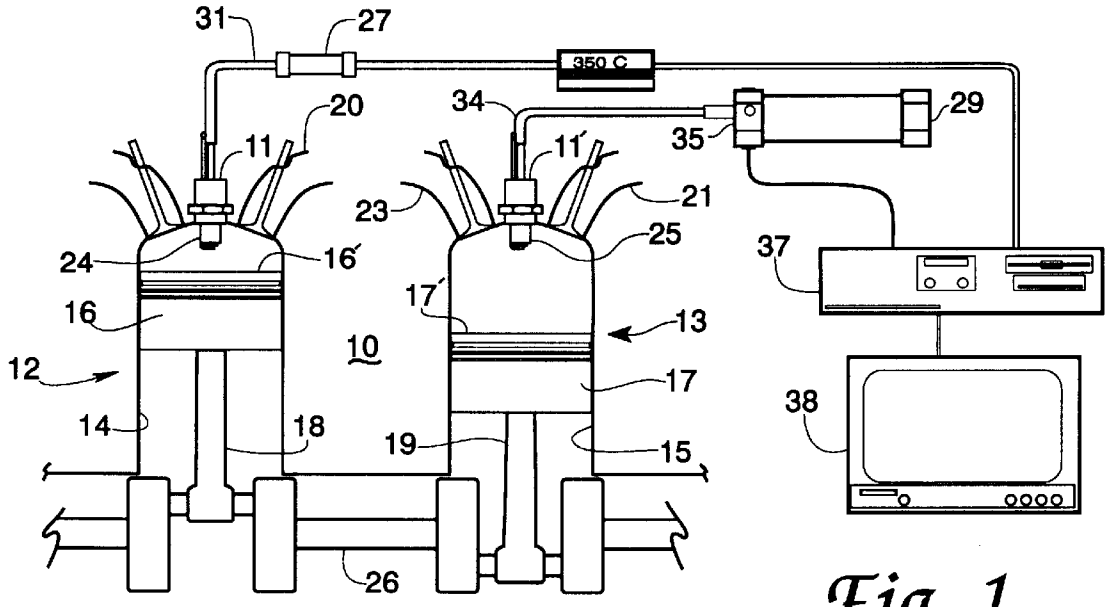

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Fig. 1

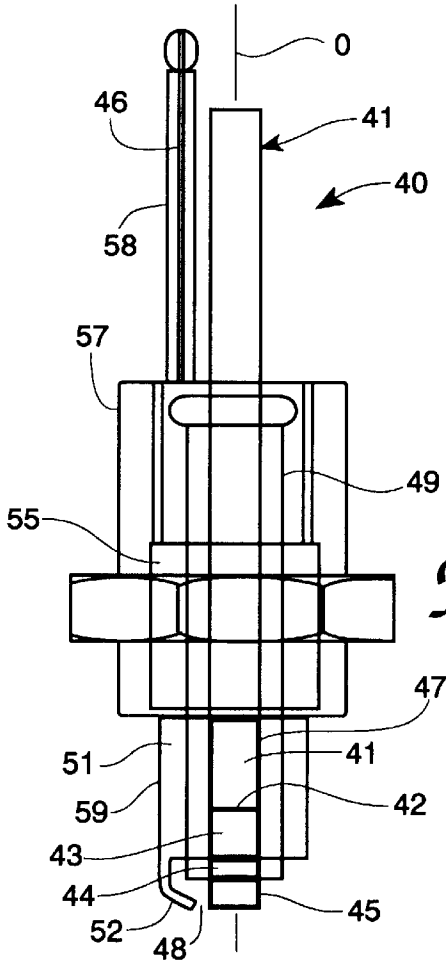
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Fig. 2

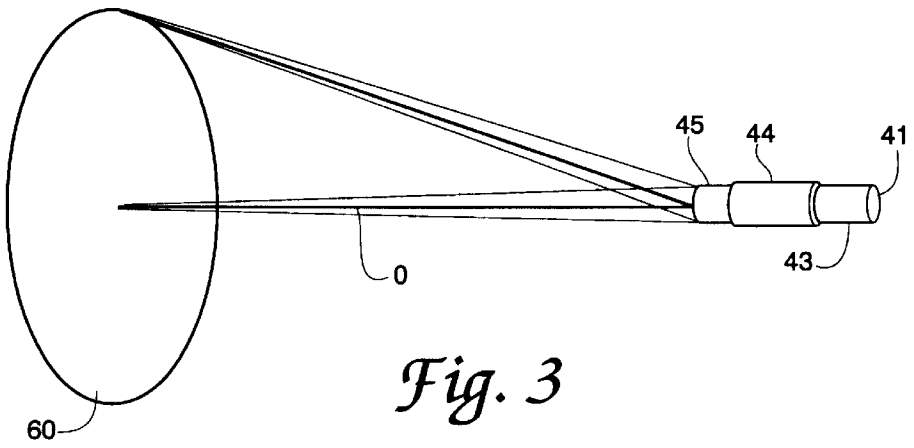

Fig. 3

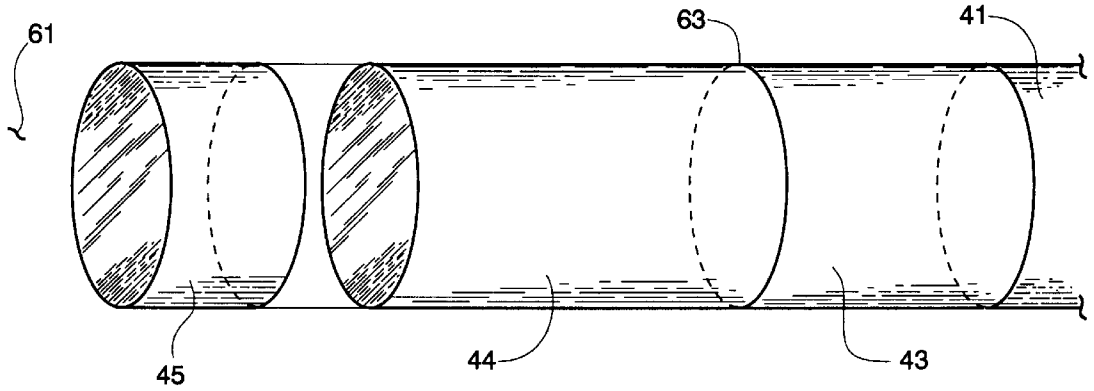

Fig. 4

INSTRUMENTATION SPARK PLUG

RIGHTS OF THE GOVERNMENT

BACKGROUND OF THE INVENTION

The present invention relates generally to systems and methods for the diagnostic testing of internal combustion engines and more particularly to an instrumented spark plug useful for optically viewing the interior of a combustion chamber of an operating internal combustion engine.

The invention provides an instrumented spark plug system for measuring the thermal profile across a piston surface within an internal combustion engine during normal operation, and includes a coherent optical fiber bundle contained within a specially constructed spark plug, and lens system optically connected to a high speed triggerable imaging infrared (IR) video camera. The system images the piston surface onto the face of the optical fiber bundle in near real time and transmits the images to the video camera, thereby obtaining spot temperature measurements at each engine cycle.

It is therefore a principal object of the invention to provide an instrumented spark plug.

It is another object of the invention to provide a system for the diagnostic testing of an internal combustion engine.

It is a further object of the invention to provide a system for obtaining temperature profile information on a piston within an operating internal combustion engine.

It is a further object of the invention to provide an instrumented spark plug for diagnostic testing of an internal combustion engine.

These and other objects of the invention will become apparent as a detailed description of representative embodiments proceeds.

SUMMARY OF THE INVENTION

In accordance with the foregoing principles and objects of the invention, a spark plug system for measuring the thermal profile across the surface of a piston in an operating internal combustion engine in characterizing the combustion process within a combustion chamber of the engine is described that includes a specially constructed spark plug containing a coherent fiber optic bundle and lens system optically connected to a high-speed triggerable imaging infrared video camera.

DESCRIPTION OF THE DRAWINGS

The invention will be more clearly understood from the following detailed description of representative embodiments thereof read in conjunction with the accompanying drawings wherein:

FIG 1 shows schematically two cylinders of an internal combustion engine and placement of the instrumented spark plug and associated equipment of the invention;

FIG. **2** is a view in axial section of a spark plug of the FIG. **1** system;

FIG. **3** is a schematic of representative imaging optics for imaging a piston surface onto the coherent fiber optic array of the system of FIGS. **1** and **2**; and

FIG. **4** is an enlarged view of the imaging optics of FIG. **3**.

DETAILED DESCRIPTION

In the drawings, FIG. **1** shows schematically two adjacent or complementary cylinders **12,13** of an internal combustion

engine **10** (e.g. cylinders **1** and **4** of a conventional eight-cylinder gasoline engine), cylinders **12,13** being equipped with instrumented spark plugs **11,11'** of the invention. Cylinders **12,13** typically include respective combustion chambers **14,15**, pistons **16,17**, piston rods **18,19**, fuel intake ports **20,21**, exhaust ports **22,23**, spark plug wells **24,25** and cam **26** operatively connected to rods **18,19**. In the representative system of the invention of FIG. **1**, two separate embodiments are presented for temperature observation of surfaces **16',17'** of pistons **16,17**.

In FIG. **1**, incoherent fiber optic bundle **31** operatively connects plug **11** on cylinder **12** to the sensor head of spot temperature sensor **27** (commercially available remote sensing thermometer) for measuring the temperature of a spot on surface **16'** of piston **16**. Coherent fiber optic bundle **34** connects plug **11'** on cylinder **13** to relay optical system **35** and IR imaging radiometric temperature sensor **29** (e.g. platinum silicide IR video camera) for imaging surface **17'** of piston **17** and producing a temperature profile across surface **17'**. Any suitably temperature resistant fiber optic bundle may be used as selected by one skilled in the applicable art guided by these teachings, an arsenic-selenium-tellurium imaging fiber bundle operating at wavelengths of about 3–5 microns (μm) being preferred and included in a system built and operated in demonstration of the invention. Fiber bundle **31** in the demonstration system was about one meter long with individual fibers having a 125 μm diameter core and 10 μm thick cladding, giving fiber-to-fiber spacing of about 135 μm.

Conventional personal computer **37** may provide means for controlled temperature data acquisition and image capture for displaying the imagery on monitor **38**. Measurements may be made at any selected position of the piston **16,17** strokes using triggering off cam **26**.

Referring now to FIG. **2**, shown therein is a view in axial section of an instrumented spark plug **40**, similar in structure to plugs **11,11'** of FIG. **1**, representative of the invention. For optimum operation of the invention, plug **40** should be structured for operating as a normal spark plug but be capable also of relaying the maximum practical optical energy characterizing the piston surface. Plug **40** therefore includes a central coherent optical fiber bundle **41** having at first end **42** thereof one or more imaging lenses **43,44** and an optical window **45** of sapphire, diamond, zinc selenide or other suitable temperature resistant optical material transparent to the wavelength range of interest (3–5 μm). Lenses **43,44**, fiber bundle **41** and window **45** are all axially aligned central of the structure of plug **40** in order to minimize effects of engine vibration and reflection losses. Fiber bundle **41** is surrounded by electrically conducting tube **47** serving as a charge carrier (cathode) to spark gap **48**. Fiber bundle **41** and conducting tube **47** are surrounded by tubular ceramic insulator **49** composed of any suitable material customarily used in conventional spark plug construction. Typical dielectric strengths of extruded type ceramics useful for insulator **49** range from about 400 to 800 volts/mil and the spark plug generates up to about 30,000 volts under full load. Insulator **49** is therefore about 80 mils thick for adequate insulation. Insulator **49** separates tube (cathode) **47** of plug **40** from the main body (anode) **51** which terminates in tip **52** and defines spark gap **48** between tip **52** and tube **47**. Spark gap **48** is disposed to one side of optical axis O along which fiber bundle **41**, lenses **43,44** and window **45** are disposed, which allows line-of-sight measurement of the surface of the piston (not shown in FIG. **2**) within its combustion chamber. Water jacket **55** may be included in the structure of plug **40** as suggested in FIG. **2** and operatively connected to a source (not shown) of coolant water to avoid overheating of plug **40** constituent parts from engine heat during operational use of the invention. Thermally insulat-

ing outer shells **57,58** of material such as DELRIN®, any suitable ceramic, or the like may be included to insulate cathode **46** and conducting tube **47** from engine heat. Means such as threads **59** may be included on the outer surface of plug **40** so that plug **40** may be received by engine **1**O as suggested in FIG. **1**.

The size of a standard spark plug requires that the instrumented plug of the invention include miniature lenses **43,44** for transmitting an image of the piston surface into fiber bundle (**41**, FIG. **2**). Lens requirements for the instrumented plug may be determined using a PC based lens design program such as ZEMAX (mfgd by Focus Software, Inc.). FIGS. **3** and **4** are schematic illustrations of representative two-lens imaging optics suitable for imaging a surface **60** of a piston onto the optical fiber bundle **41** of the invention. Optical window **45** (nominally 1 inch thick sapphire) protects imaging lenses **43,44** from the heat of combustion chamber **61**. Lenses **43,44** are nominally about 6 mm in diameter in order to accommodate size restrictions imposed on plug **40**, and may comprise any suitable materials as would occur to the skilled artisan guided by these teachings, such as germanium or zinc selenide as illustrated in FIG. **4**. Lenses **43,44** are cemented together and fiber bundle **41** is cemented to the back side of lens **44** as suggested in FIG. **4** using conventional IR index matching cement **63**. The first (input) surface of lens **43** serves as the stop and may preferably have an antireflection coating . Lenses **43,44** correct some field curvature, coma, astigmatism and spherical aberrations and image the scene onto the input surface of fiber bundle **41**.

The invention therefore provides an instrumentation spark plug for viewing the combustion process within a combustion chamber of an internal combustion engine. It is understood that modifications to the invention may be made to the invention as might occur to one with skill in the field of the invention within the scope of the appended claims. All embodiments contemplated hereunder which achieve the objects of the invention have therefore not been shown in complete detail. Other embodiments may be developed without departing from the spirit of the invention or from the scope of the appended claims.

I claim:

1. A spark plug system for measuring the thermal profile across the surface of a piston in an operating internal combustion engine, comprising:

(a) an optical fiber having first and second ends disposed along an optical axis;

(b) an imaging lens disposed at said first end of said optical fiber and axially aligned therewith for transmitting along said optical fiber an image of a surface of a piston within an operating internal combustion engine;

(c) a temperature resistant substantially optically transparent optical window on said imaging lens for protecting said imaging lens from heat within the engine;

(d) an electrically conducting tube surrounding said optical fiber, imaging lens and optical window near said first end of said optical fiber, said tube comprising a first electrode;

(e) a tubular ceramic insulator surrounding said conducting tube;

(f) means defining a second electrode external of said tubular ceramic insulator, said second electrode terminating at one end thereof near said first end of said optical fiber and defining a spark gap between said second and first electrodes near said first end of said optical fiber;

(g) means external of said second electrode for engaging a spark plug well of the engine; and

(h) means operatively connected to said second end of said optical fiber for controlled temperature data acquisition and image capture for displaying images of said piston surface transmitted by said optical fiber.

2. The system of claim **1** wherein said optical window comprises a material selected from the group consisting of sapphire, diamond and zinc selenide transparent to optical wavelengths in the range of about 3 to 5 microns.

3. The system of claim **1** wherein said optical fiber comprises an arsenic-selenium-tellurium imaging fiber bundle for operation at wavelengths of about 3–5 microns.

4. The system of claim **1** wherein said imaging lens comprise a material selected from the group consisting of germanium and zinc selenide.

5. The system of claim **4** further comprising an antireflection coating on said imaging lens.

6. A spark plug system for measuring the thermal profile across the surface of a piston in an operating internal combustion engine, comprising:

(a) an optical fiber having first and second ends disposed along an optical axis;

(b) an imaging lens disposed at said first end of said optical fiber and axially aligned therewith for transmitting along said optical fiber an image of a surface of a piston within an operating internal combustion engine;

(c) a temperature resistant optical window on said imaging lens for protecting said imaging lens from heat within the engine, said optical window being substantially transparent to optical wavelengths in the range of 3 to 5 microns;

(d) an electrically conducting tube surrounding said optical fiber, imaging lens and optical window near said first end of said optical fiber, said tube comprising a first electrode;

(e) a tubular ceramic insulator surrounding said conducting tube;

(f) means defining a second electrode external of said tubular ceramic insulator, said second electrode terminating at one end thereof near said first end of said optical fiber and defining a spark gap between said second and first electrodes near said first end of said optical fiber; and

(g) thread means external of said second electrode for threadably engaging a spark plug well of the engine.

7. The system of claim **6** further comprising an imaging radiometric temperature sensor operatively connected to said second end of said optical fiber for imaging the surface of the piston.

8. The system of claim **6** further comprising a remote sensing thermometer operatively connected to said second end of said optical fiber for measuring the temperature of the surface of the piston.

9. The system of claim **6** wherein said optical window comprises a material selected from the group consisting of sapphire, diamond and zinc selenide.

10. The system of claim **6** wherein said optical fiber comprises an arsenic-selenium-tellurium imaging fiber bundle for operation at wavelengths of about 3–5 microns.

11. The system of claim **6** wherein said imaging lens comprises a material selected from the group consisting of germanium and zinc selenide.

12. The system of claim **11** further comprising an antireflection coating on said imaging lens.

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